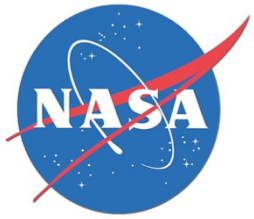

Upward-Pointing Cosmic-Ray-like Events Observed with ANITA

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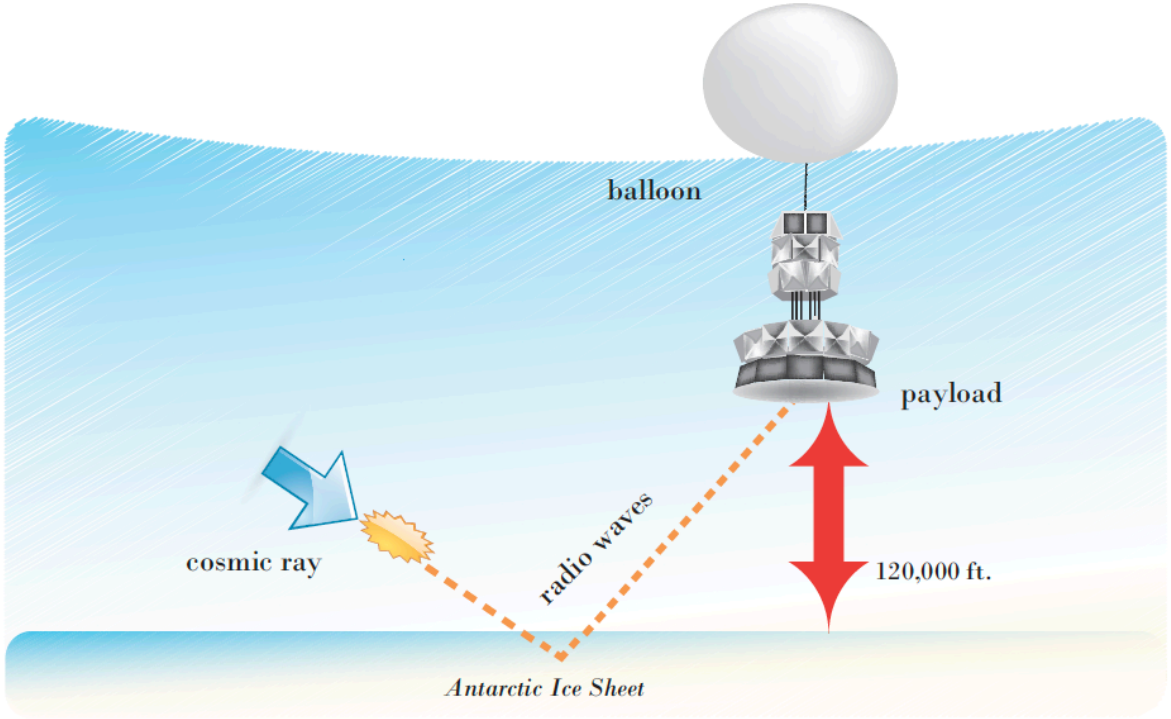
Extensive Air Showers with ANITA

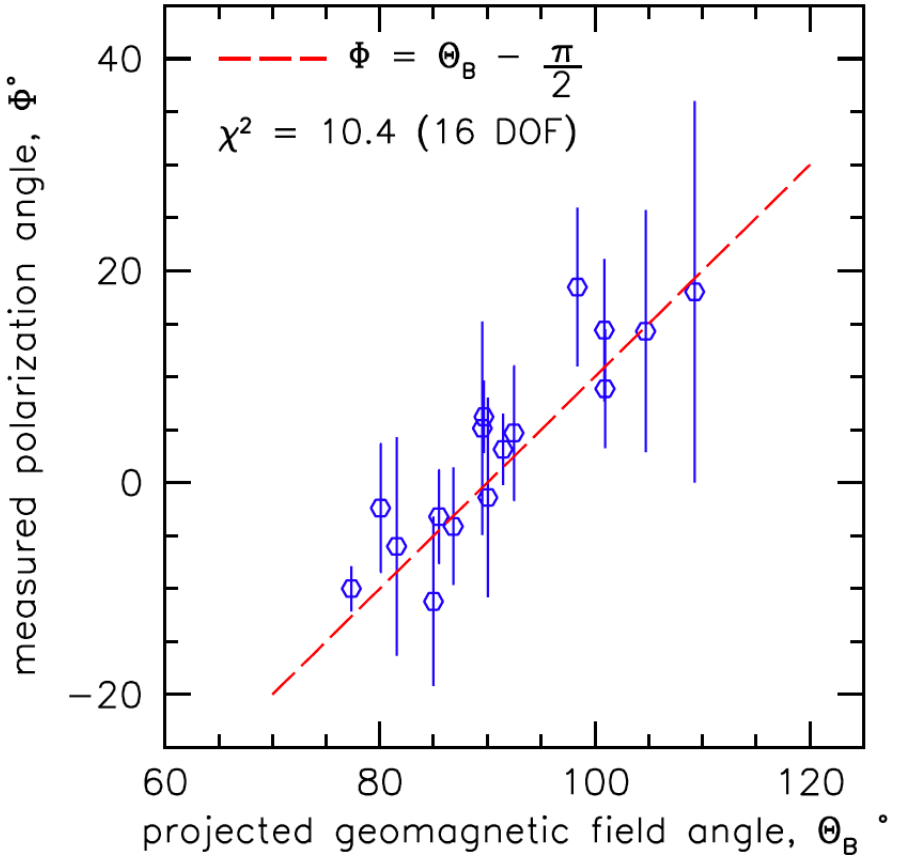
- ANITA is a balloon borne instrument for radio detection of ultra-high energy neutrinos.
- Unexpectedly, the first flight of ANITA observed radio emission from extensive air showers reflected off the ice sheet (Hoover et al., 2010)



Credit: S. Hoover dissertation

Extensive Air Shower Identification

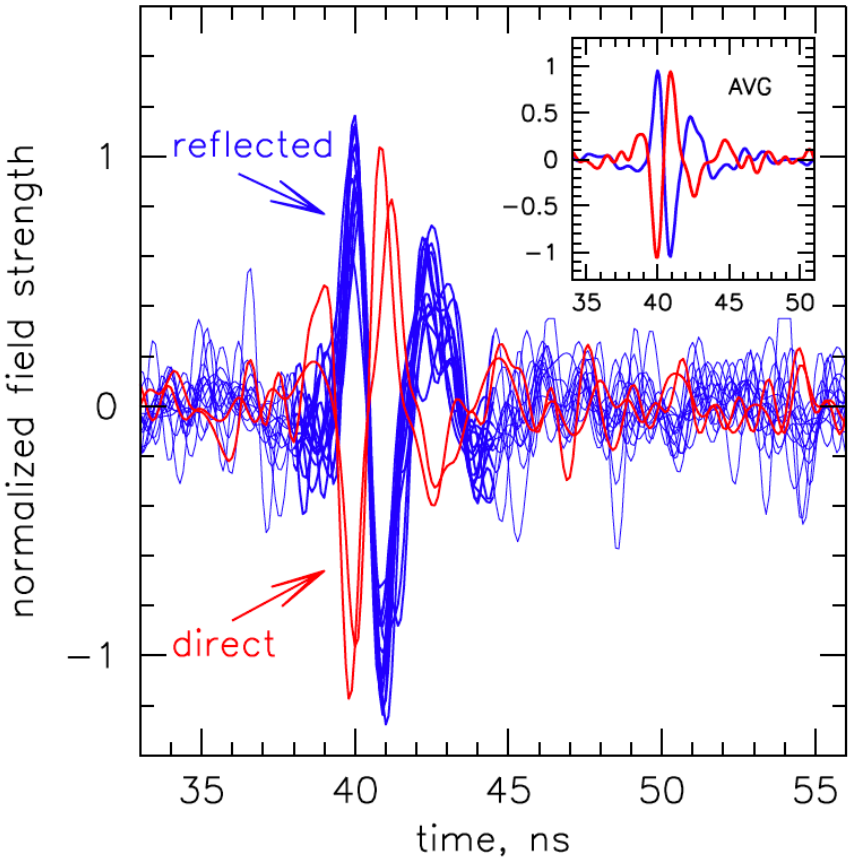
- EAS events are identified by the correlation of the polarization angle to the geomagnetic field angle.



Credit: S. Hoover et al., PRL, 2010

Extensive Air Showers Impulse

- Impulse shape is similar between all events.
- Impulse has exponentially falling spectrum.
- 3 above-horizon events were observed with ANITA-1
- Direct events are identified by their direction and polarity.

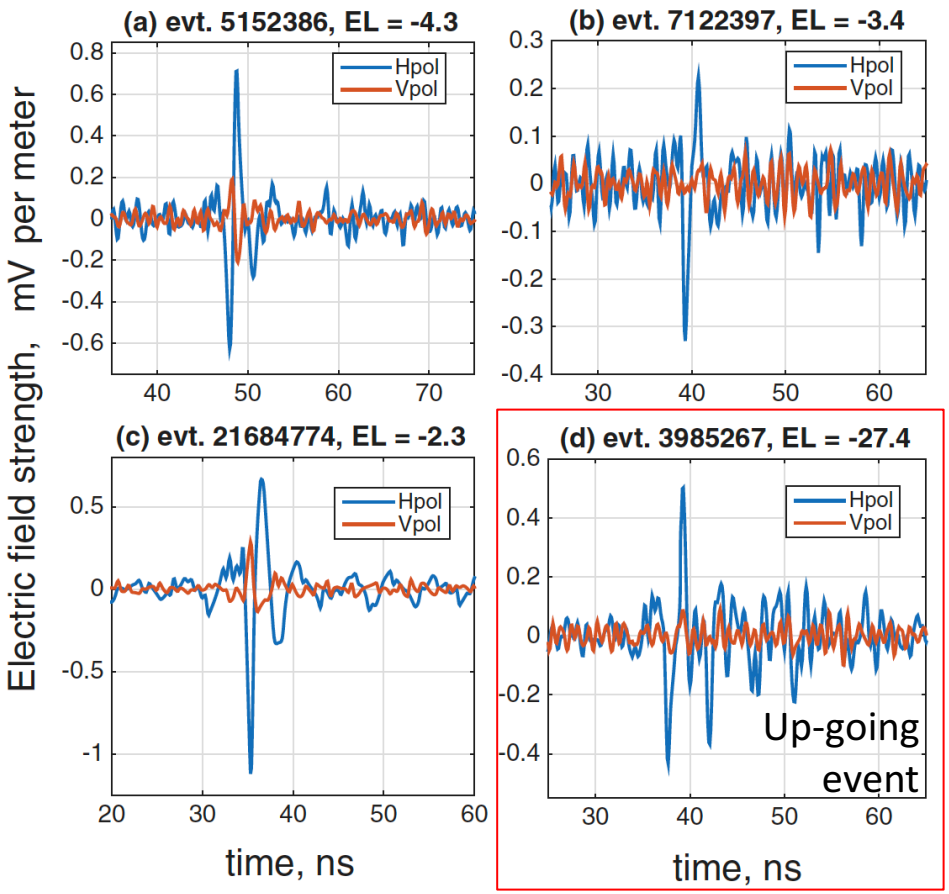


Credit: S. Hoover et al., PRL, 2010

Upward-Pointing Events

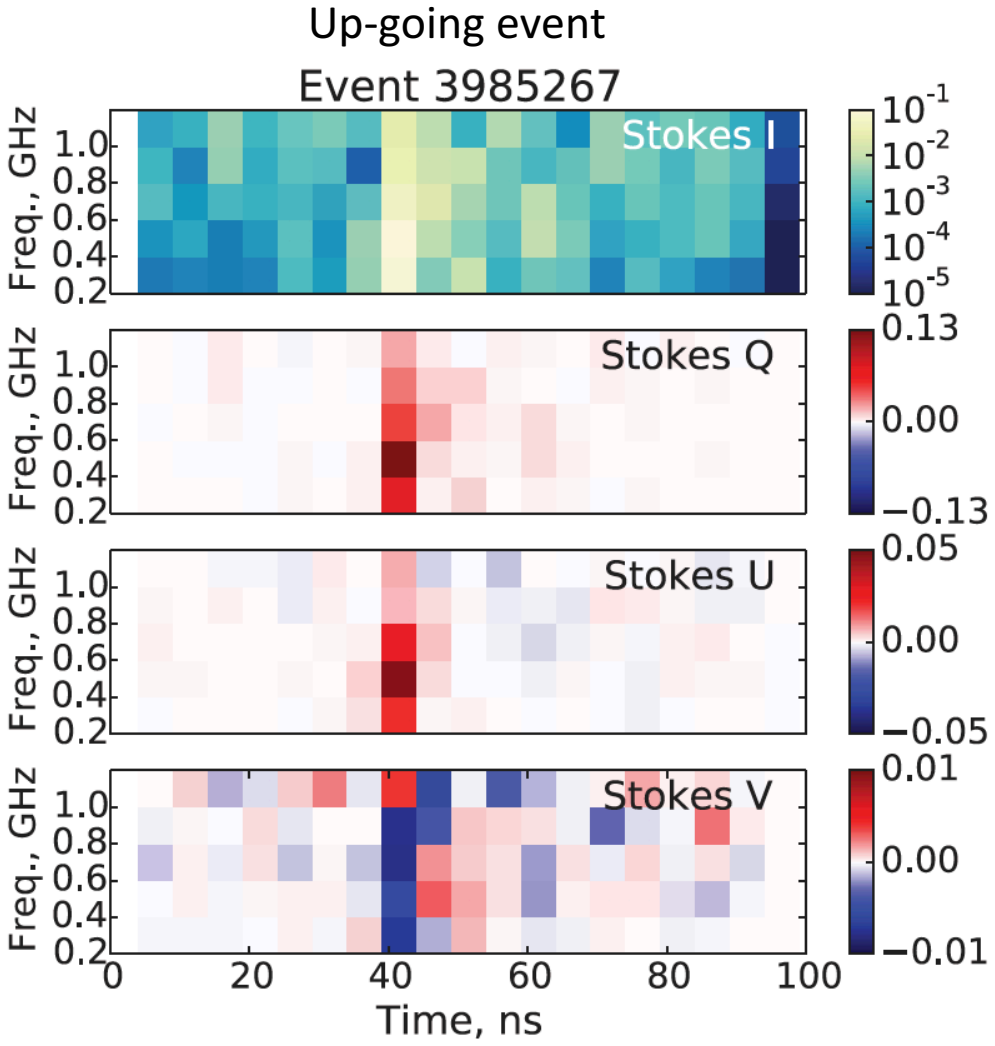
- One **up-going** ANITA event that passed blind analysis cuts (red square) pointed to the ice sheet but did not have the polarity of a reflected event.
- This is consistent with an extensive air shower pointing up from the ground.
- Such signals could arise from decay of up-going τ-lepton of neutrino origin.

Credit: Gorham et al., PRL, 2016



Circular Polarization of EAS Events

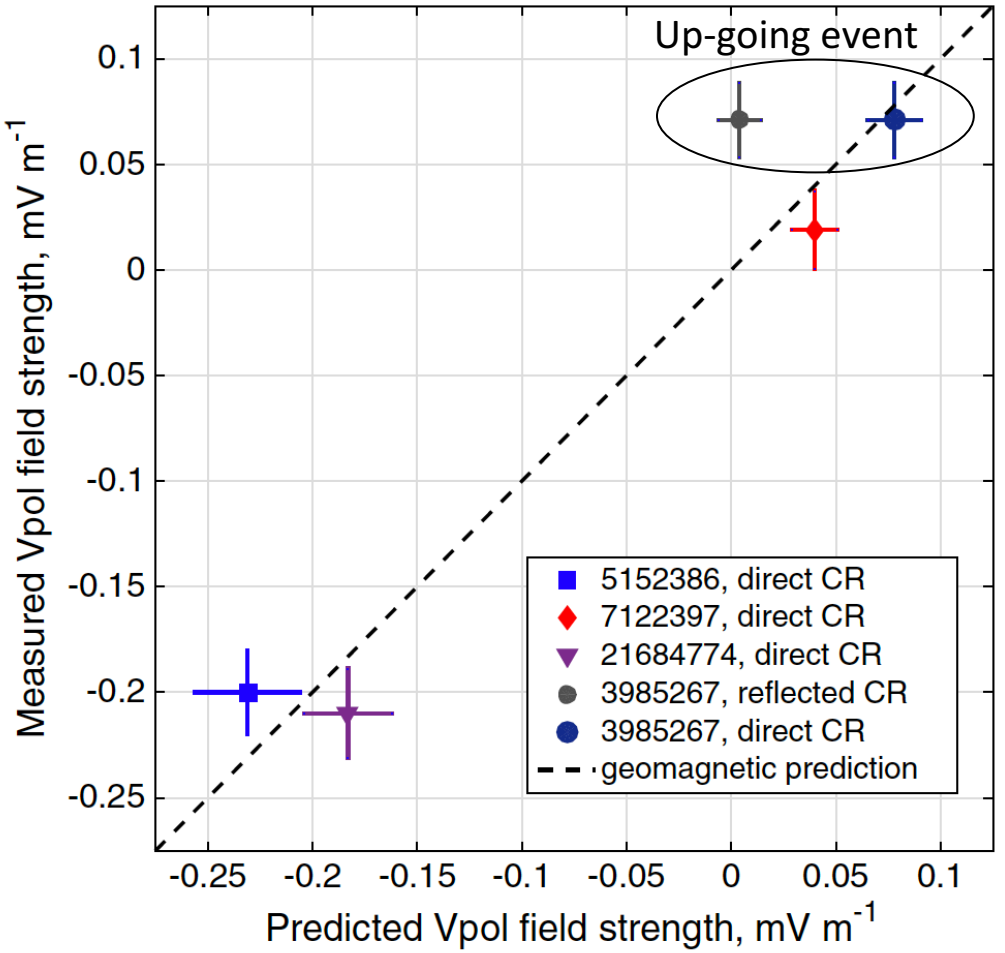
- EAS events can have a significant fraction of circular polarization (Stokes V) with LOFAR (Scholten et al., PRL, 2016)
- Down-going direct events have up to 25% circular polarization fraction.
- Up-going event has 10% circular polarization fraction.



Credit: Gorham et al., PRL, 2016

Geomagnetic Polarization

- The geomagnetic polarization vector is different at Xmax for a reflected down-going EAS compared to a direct up-going EAS.
- The event is consistent with Xmax for an up-going geometry.
- Down-going reflected hypothesis is discrepant by 2.5σ.

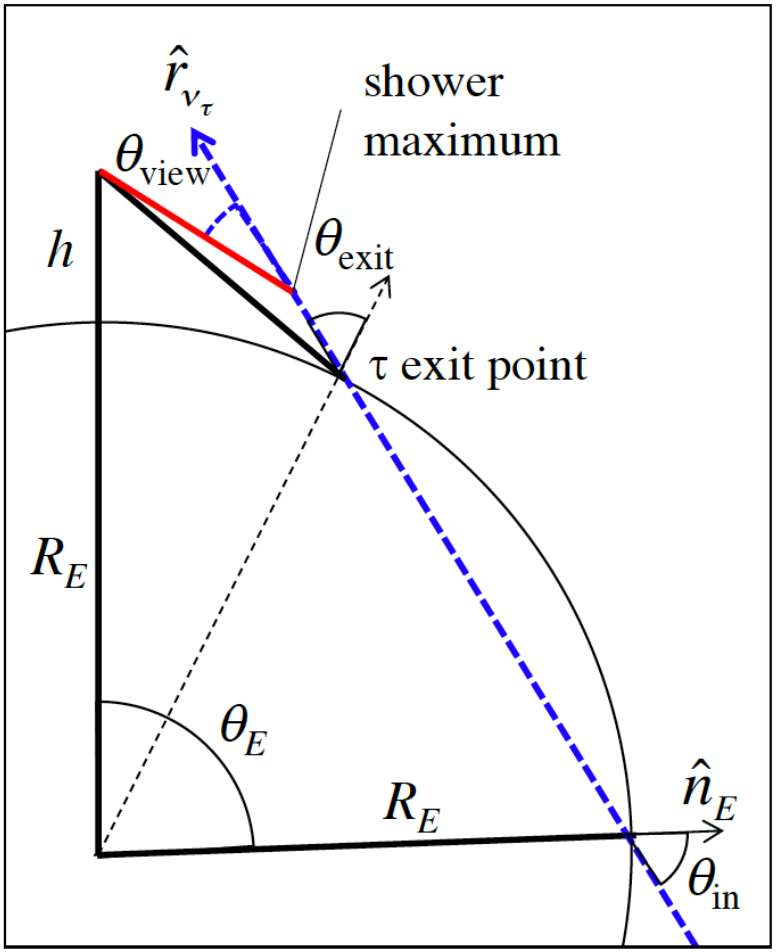


Competing Hypotheses for Up-Going EAS Event

Hypothesis	Discrimintation
Anthropogenic Background	• Anthropogenic backgrounds tested against 80,000 clustered events. • Estimated probabilities of impulse shape, geomagnetic polarization, and Stokes V contents • Estimated number of isolated background events is 1.6 • Including trials factor, we expect $N=4\times10^{-4}$ background events. • EAS hypothesis is favored but not enough to exclude this possibility.
Reflected Down-going EAS Event	• Geomagnetic polarization is inconsistent at the 2.5σ level. • Polarity mis-identification is negligible given high SNR.

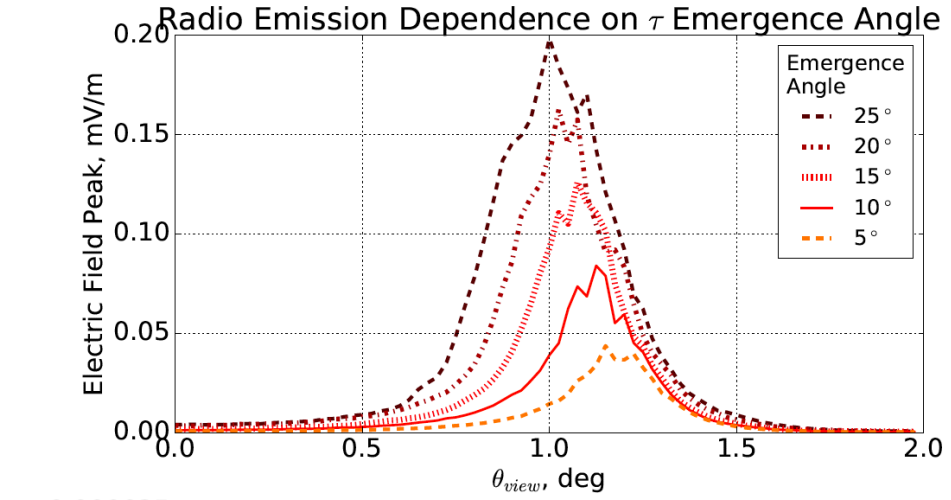
τ-lepton hypothesis

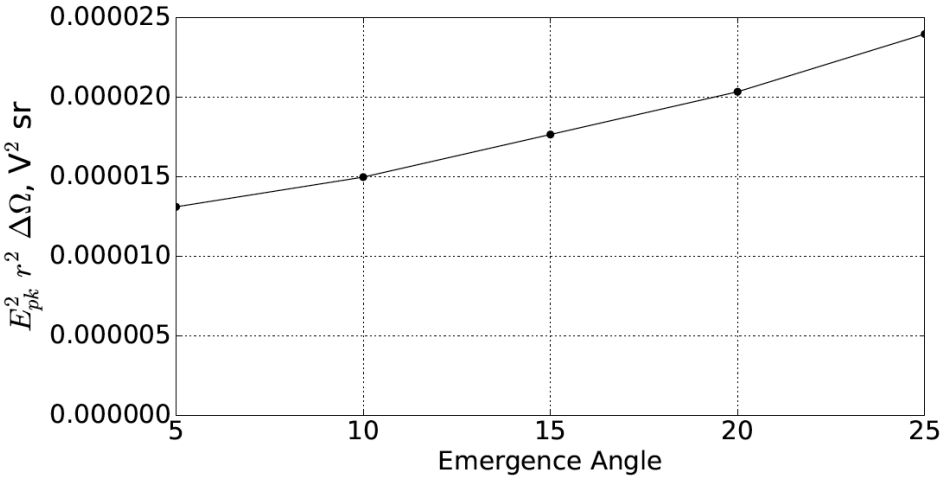
- Estimate the exposure for τ-lepton decays of τ-neutrino
- A τ-neutrino enters the Earth, producing a τ-lepton that exits the crust.
- The τ-lepton produces an EAS detected by ANITA.
- We produced **upper bounds** of the exposure for this process.



Radio Emission of Up-Going EAS

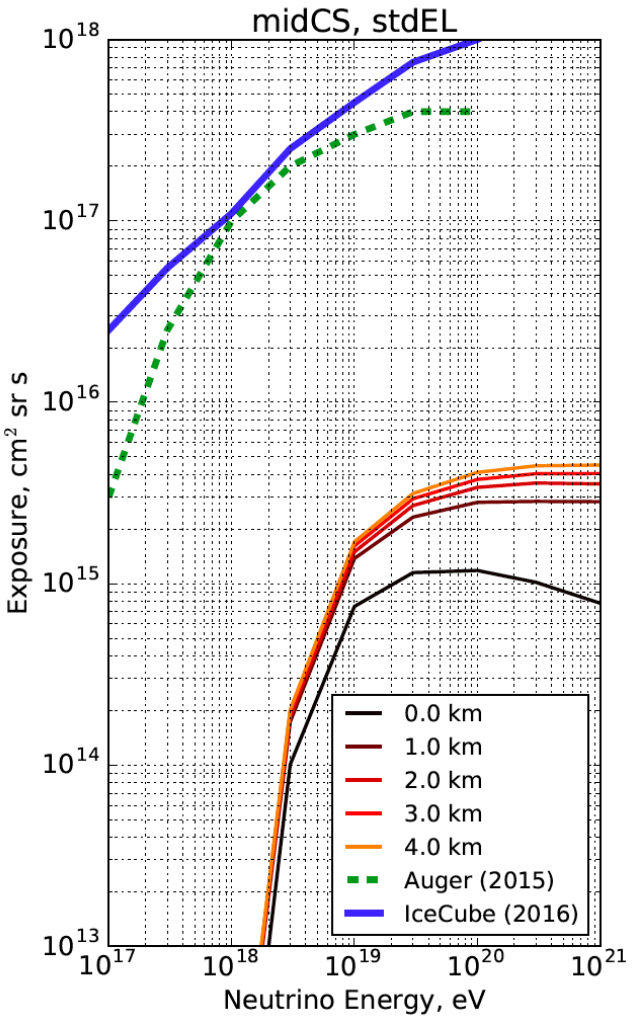
- Produced a set of simulations using ZHAireS for the geometries relevant to the ANITA event.
- For the **upper bound** estimate, we took the radio emission profile that radiates the most power.
- This corresponds to emergence angle of 25 degrees with the decay occurring on the ground.





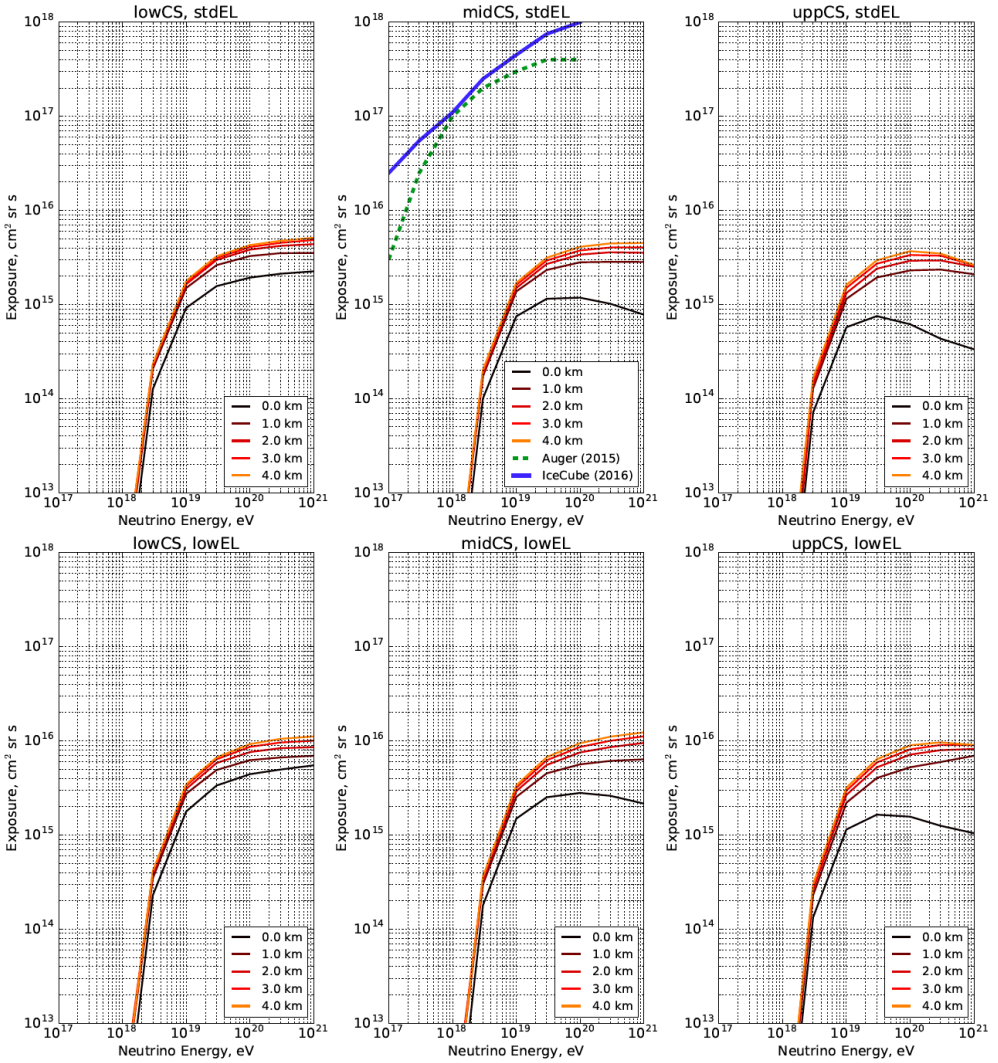
Upper Bounds on ANITA Exposure

- Assumed standard values of the neutrino cross-section and tau energy loss.
- Studied the effect of ice-shell thickness.
- Find that Auger and IceCube exposures are ~100 times larger.
- Given neutrinos at UHE have not been detected, this makes the ANITA event τ-lepton decay unlikely



Upper Bounds on ANITA Exposure

- We also studied the effect of varying the interaction models within SM uncertainties.
- Upper bounds on the exposure do not vary significantly enough to compensate.
- However, we do not have the dependence on SM uncertinaties for Auger and IceCube so the comparison is inconclusive.



Conclusions

- The origin of the up-going cosmic-ray-like ANITA event remains a mystery.

- The possibility that going outside of the standard model results in the possibility of the ANITA event being a t-lepton decay without tension from Auger and IceCube remains to be explored

- Results from on-going analysis of ANITA-3 and ANITA-4 have the potential to confirm or falsify the astrophysical origin of this event.

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